Development of TMDL Nutrient End-Point for the Jackson River

Submitted to

Virginia Department of Environmental Quality

Prepared by

THE Louis Berger Group, INC.

2300 N Street, NW
Washington, DC 20037

June 2006

Development of TMDL Nutrient End-Point for the Jackson River

1. Introduction

This document presents the approach used in developing the nutrient TMDL endpoint in the Jackson River. The Benthic Stressor Identification Report indicated that the most probable stressor in the Jackson River is the excessive periphyton growth in the stream. The excessive periphyton impairs benthic macroinvertebrates assemblages by covering the interstitial spaces between rocks and cobble that comprise much of the habitat for many types of invertebrates. This excessive periphyton growth is caused by excessive nutrient loading. Consequently, reductions in nutrient are necessary to replenish and maintain the benthic macroinvertebrate community in the Jackson River. The development of TMDL end-point consists of the following:

- The first step is to identify the benthic chlorophyll[1] levels that are acceptable and amenable in restoring the benthic community in the Jackson River. Based on previous work, benthic chlorophyll levels in streams that range from 100-150 mg/m^2 are considered excessive and at nuisance level (Welch et al. 1988). Chlorophyll *a* is a photosynthetic pigment in algae and used as an indicator of algal biomass (Barbour *et al*., 1999). Consequently, benthic chlorophyll levels below or at 100 mg/m^2 are the periphyton TMDL endpoint in the Jackson River.

- The second step is to establish a link between the benthic chlorophyll threshold of 100 mg/m^2 and the instream nutrient concentrations (TN and TP). These nutrient concentrations, corresponding to benthic level of 100 mg/m2, are the nutrient TMDL end-points in the Jackson River. This is the main focus of this document; developing relationship between benthic chlorophyll and nutrient observations in the Jackson River for the identification of these endpoints.

2. Development of Predictive Empirical Model using Regression Analysis

Predictive empirical models are commonly used in water quality modeling and assessment. Empirical models, which are often based on statistical relationships, attempt to establish correlations between key variables. In our case, we use the extensive water quality monitoring data in the Jackson River to determine how water column nutrients are linked to periphyton and try to identify if there are strong relationships between stream benthic algae and nutrients in the Jackson River.

Empirical regression models that link algal biomass (phytoplankton) and water column nutrients have been used successfully in the eutrophication management of freshwater lakes and reservoirs (Smith 1998, 1999), (Cooke et al. 1998). Similarly, empirical regression models have been recently developed by Dodds et al. (2002) using multiple regression analysis between periphyton and water-column nutrients from rivers located in USA and New Zealand. The results of this analysis showed that the mean benthic biomass in these streams was explained by about 40% (R-square = 0.4) by concentrations of Total N and Total P. The disadvantage of such a relationship, developed by Dodds (2002), is that it applies to streams that are not specific to a region or a stream. However, Dodds' relationship was recently used in the development of the nutrient endpoint of the periphyton TMDL in Skippack, PA (PADEP, 2005). PADEP attempted to develop a specific regression for the Skippack Watershed, but was unsuccessful due to the limited amount of data (Periphyton, water-column nutrients).

Because of the extensive monitoring data available in the Jackson River, we propose to develop a regression model between the periphyton and the water-column nutrients specific to the Jackson River.

[1] Chlorophyll *a* is referred simply as chlorophyll throughout the document.

3. Regression Analysis - Periphyton and Nutrients in the Jackson River

Extensive ambient monitoring was performed between 2000 and 2002 as part of the implementation of a water quality model in the Jackson River (MeadWestvaco 2003). In addition, VADEQ has an extensive monitoring program at different stations in the Jackson River. The data include nutrient (N,P) and periphyton observations at several stations along mainstem the Jackson River.

The objective is to develop regression equations between benthic chlorophyll and in-stream nutrient concentrations; in other words we attempt to identify any strong relationships between water-column nutrients and periphyton biomass in the Jackson River.

First, the complete data was screened to identify observations containing simultaneous TN, TP, and benthic chlorophyll (only data collected during the same day are included in the analysis). A total of 158 observations of benthic chlorophyll and nutrient species were used to develop the regressions (Table 4). These water quality observations were measured during the months of June trough October. The observations from all the stations in the Jackson River were combined in one data set (including stations upstream and downstream of MeadWestvaco). The statistical package Minitab® (Version 14) was used to develop these regressions in order to attempt to explain any eventual relationship between nutrient and benthic algae.

4. Summary of Results

The nutrient data, recorded simultaneously with benthic chlorophyll, consist of NH_3-N, NO_2, NO_3, PO_4, total dissolved nitrogen (TDN), and total dissolved phosphorus (TDP). First, a single regression analysis was developed between benthic chlorophyll and each of the nutrient species. Then using a multiple regression analysis, a relationship was developed between chlorophyll, TDN, and TDP. The objective is to identify any meaningful relationship between the variables in the dataset. Table 1 shows the result of this analysis.

Table 1. Regression models for Benthic Chlorophyll as a Function of nutrients in the Jackson River

Dependent Variable (Response)	Independent Variable 1	Independent Variable 2	Intercept	R-square	Adjusted R-square
Log Chla	0.400*Log(NH4)	-	2.63	0.093	0.087
Log Chla	-0.544*Log(NO3)	-	1.57	0.023	0.017
Log Chla	0.423*Log(PO4)	-	2.60	0.597	0.594
Log Chla	2.43*Log(TDN)	-	2.90	0.293	0.289
Log Chla	0.543*Log(TDP)	-	2.62	0.602	0.599
Log Chla	0.524*Log(TDP)	0.178*Log(TDN)	2.66	0.603	0.598

The results from this data analysis clearly show that total phosphorus or PO4 explain approximately 60% of the variation in benthic biomass in the Jackson River. A weak relationship was derived from the nitrogen species (NH4, NO3, and TDN). However, when using TDP and TDN as independent variables and performing a multiple regression analysis, the result shows a strong relationship yielding an R-square of 0.603, indicating that the TDN and TDP, when combined, explain approximately 60% of the benthic biomass variations in the Jackson River.

5. Summary of Periphyton and Nutrient Data in the Jackson River

Prior to developing the nutrient TMDL end-point, it is necessary to summarize and present the periphyton and nutrient data at several stations in the Jackson River. Figures 1 through 3 depict the data summary.

Figure 1: TDN Data Summary

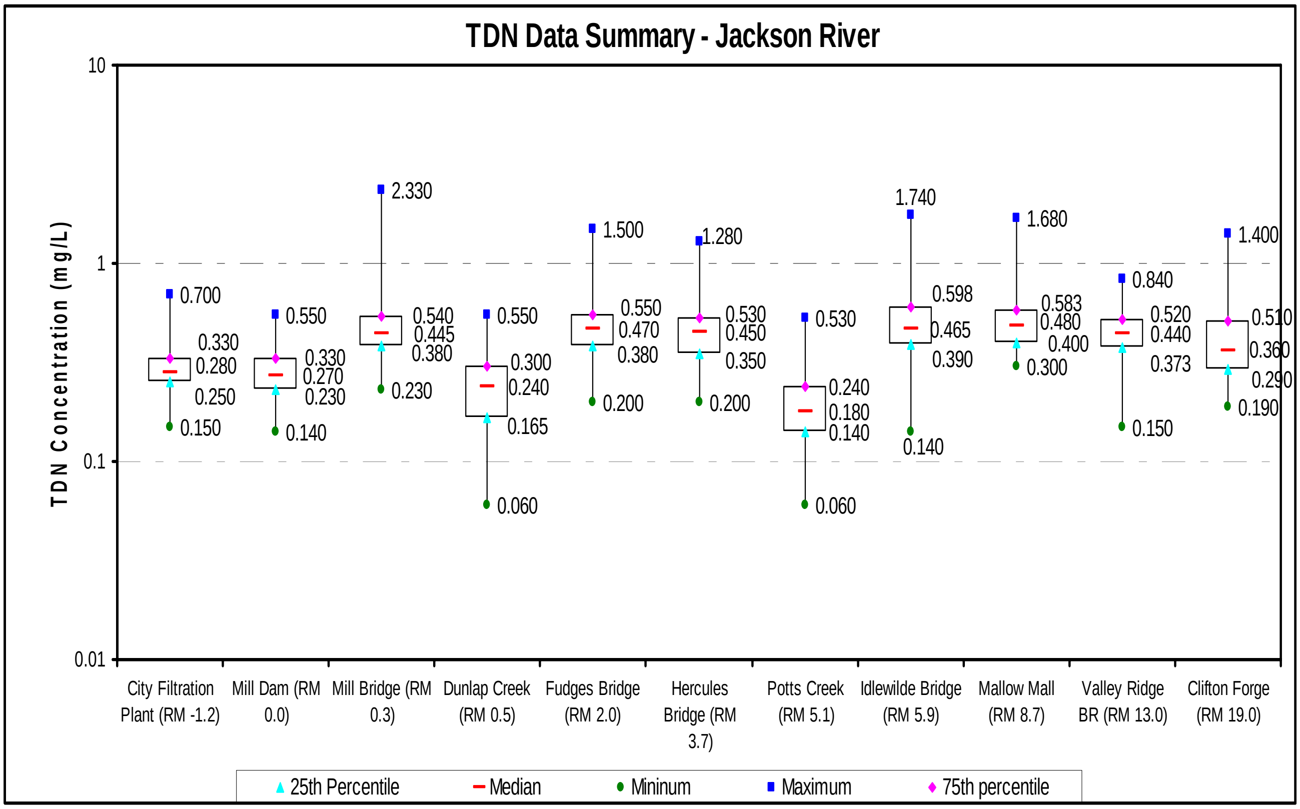


Figure 2: TDP Data Summary

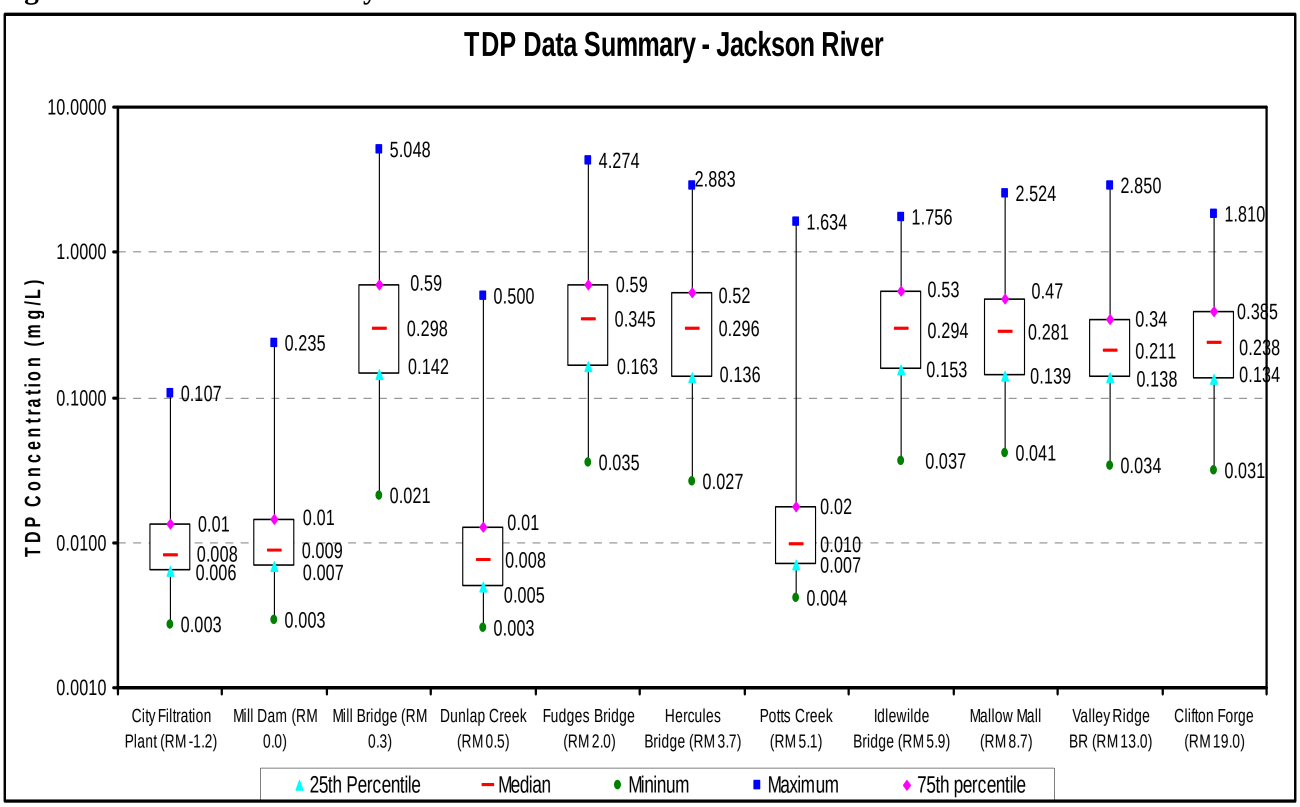
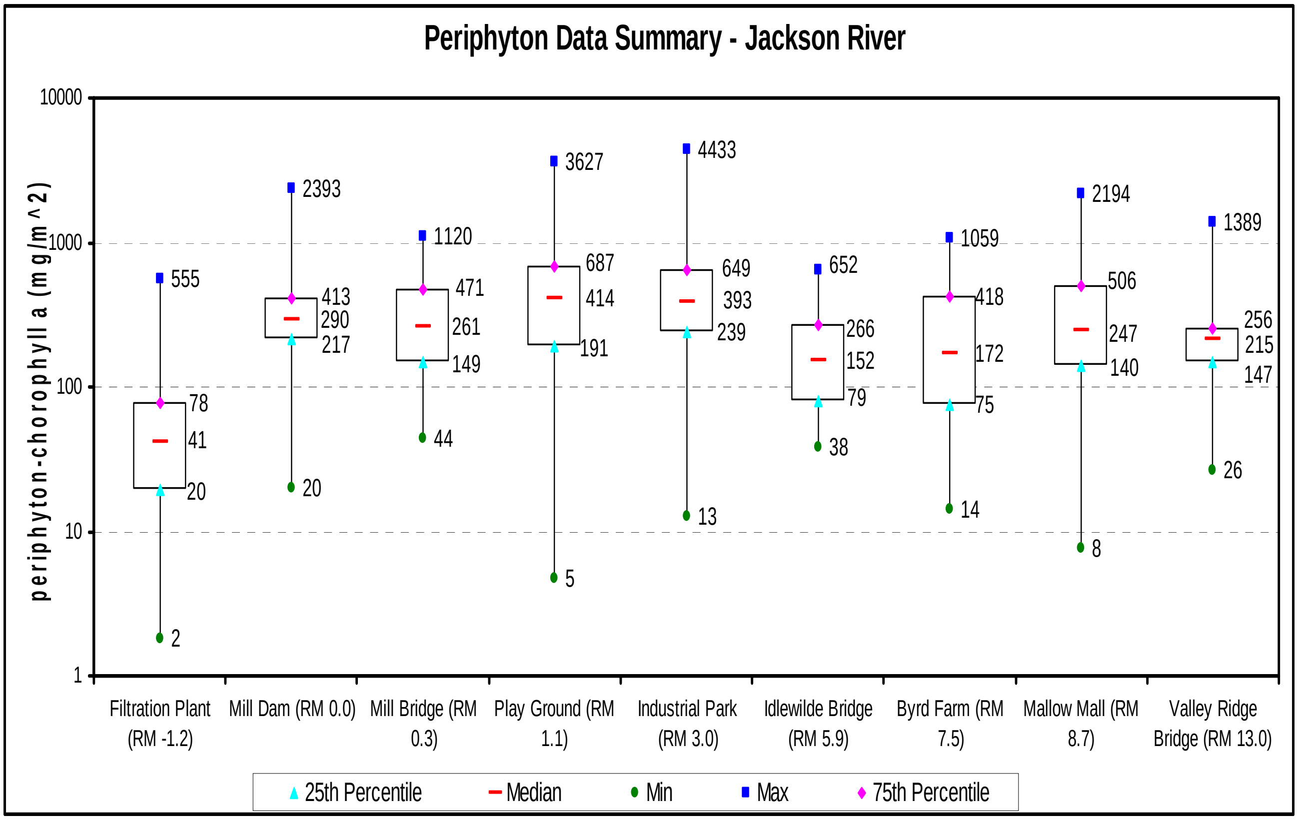


Figure 3: Periphyton Data Summary



The TDN data shown in Figure 1 indicate that TDN observations are relatively similar upstream of the MeadWestvaco discharge and in the two tributaries; Dunlap Creek and Potts Creek (median values of 0.24 mg/L). Below the MeadWestvaco discharge, TDN increases to 0.45 mg/l and remains at this level along the Jackson River.

The TDP data shown in Figure 2 indicate that TDP observations are low upstream of the MeadWestvaco discharge and in the two tributaries; Dunlap Creek and Potts Creek (median values of 0.008 mg/L, and 0.018 mg/l in Potts Creek). Below the MeadWestvaco discharge, TDP increases substantially to approximately 0.3 mg/L (median value).

The periphyton data shown in Figure 3 indicate that almost all the observations are above the 100 mg/m2 threshold discussed previously. Only one station, above the MeadWestvaco discharge (Filtration Plant), has an acceptable level of algal biomass.

Above the MeadWestvaco discharge the average N:P ratio is approximately 36, suggesting that the stream at this location is phosphorus limited. However, below the MeadWestvaco discharge the N:P ratio shifts drastically to a value of 1.2. This N:P ratio shift is due to the excessive phosphorus loading to the Jackson River.

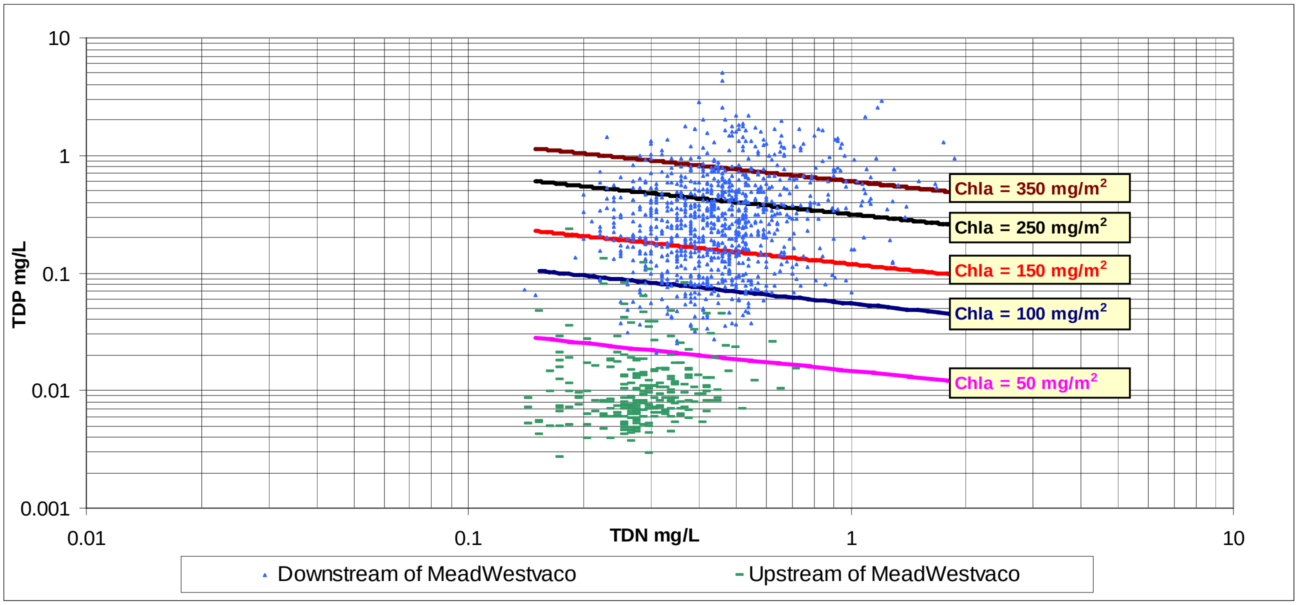
6. Discussion of the Regression Models and Development of the TMDL Endpoint

Prior to developing the phosphorus endpoint the multiple-regression, shown in Section 3, between chlorophyll, TDN and TDP **[Log (Chla) = 0.524*Log (TDP) + 0.178*Log (TDN) + 2.66 (r^2 = 0.603)]** is presented graphically and discussed. Similarly, the regression between phosphorus and TDP is also presented graphically and used to develop the final phosphorus endpoint **[Log (Chla) = 0.543*Log (TDP) +2.62 (r^2 = 0.602)].**

6.1 Multiple Regression Between periphyton-chlorophyll, TDP, and TDN

In order to visualize this three-dimensional equation, a two-dimensional plot was developed with TDN and TDP as x and y axes with the corresponding iso-periphyton-concentrations. The results of this analysis are displayed in Figure 4.

Figure 4: Periphyton and Nutrient Relationship in the Jackson River



A computer program was developed to identify the combinations of TDP and TDN concentrations resulting in specific periphyton concentrations (i.e., 100, 200, 200 mg/m2 of chlorophyll). Each solid line in Figure 4 represents a specific periphyton concentration. For instance the line labeled *"Chla =100"* represents the combinations of TDN and TDP concentrations which result to a periphyton concentration of 100 mg/m^2, using the regression equation *Log (Chla) = 0.524*Log (TDP) + 0.178*Log (TDN) + 2.66*.

In addition, Figure 4 also displays all the TDN and TDP concentrations recorded in the Jackson River (combination of N&P recorded the same day). In fact, two time series of TDN and TDP observations are displayed in Figure 4; one for the observations downstream of MeadWestvaco, and one for the observations upstream of MeadWestvaco. It should be noted that the data used for the derivation of the regression equations is a subset of the one presented in Figure 4 (TDN AND TDP Concentrations).

Figure 4 indicates that the regression reproduces quite well the observed periphyton concentrations in the Jackson River. In fact, upstream of the MeadWestvaco discharge at the Filtration Plant Station, the mean Chla concentration is approximately 58 mg/m^2 (Table 7) and is well reproduced by the line representing the 50 mg/m^2 shown in Figure 4. In addition, Figure 4 also shows that most of the observations below the MeadWestvaco discharge fall between 200 and 350 mg/m^2, which reproduce quite well the observed periphyton data shown in Figure 3.

Figure 4 also indicates that based on the regression equation, the periphyton concentrations are less sensitive to TDN reductions than to TDP reductions. This can be explained by the fact that the system is overloaded with phosphorus, and minor reductions in nitrogen have little effect on the periphyton biomass.

The results of the regression analysis presented in Section 4 indicate that the periphyton levels are strongly related to the phosphorus level in the Jackson River. This indicates that reducing the phosphorus level in the Jackson River will be more amenable in reaching an acceptable level of periphyton biomass in the Jackson River.
The multi-regression equation between Chla, TDP, and TDN is used to derive the TDP endpoints. **[Log (Chla) = 0.524*Log (TDP) + 0.178*Log (TDN) + 2.66].** Assuming that the nitrogen level remains unchanged in the Jackson

River and at 0.49 mg/L (mean of all the means at all the stations except Filtration Plant, Dunlap, and Potts; Table 5); TDP levels of 0.070 mg/L are needed to achieve a periphyton concentration 100 mg/m^2.

6.2 Regression Between periphyton-chlorophyll, and Total Dissolved Phosphorus

For the development of the phosphorus endpoint in the Jackson River we will use the relationship between TDP and periphyton-chlorophyll: **[Log (Chla) = 0.543*Log (TDP) +2.62 (r^2 = 0.602)]**. Figure 5 presents the results of the regression analysis with all the data points used and Figure 6 displays this regression along with the corresponding TDP concentration for a periphyton concentration of 100 mg/m^2. As shown in Figure 6, this relationship results in an average TDP concentration of 0.072 mg/L corresponding to an average periphyton concentration of 100 mg/m^2. It should be noted that this endpoint is similar to the one derived using the multiple relationship between Chla, TDP, and TDN.

Figure 5: Periphyton and TDP Regression in the Jackson River

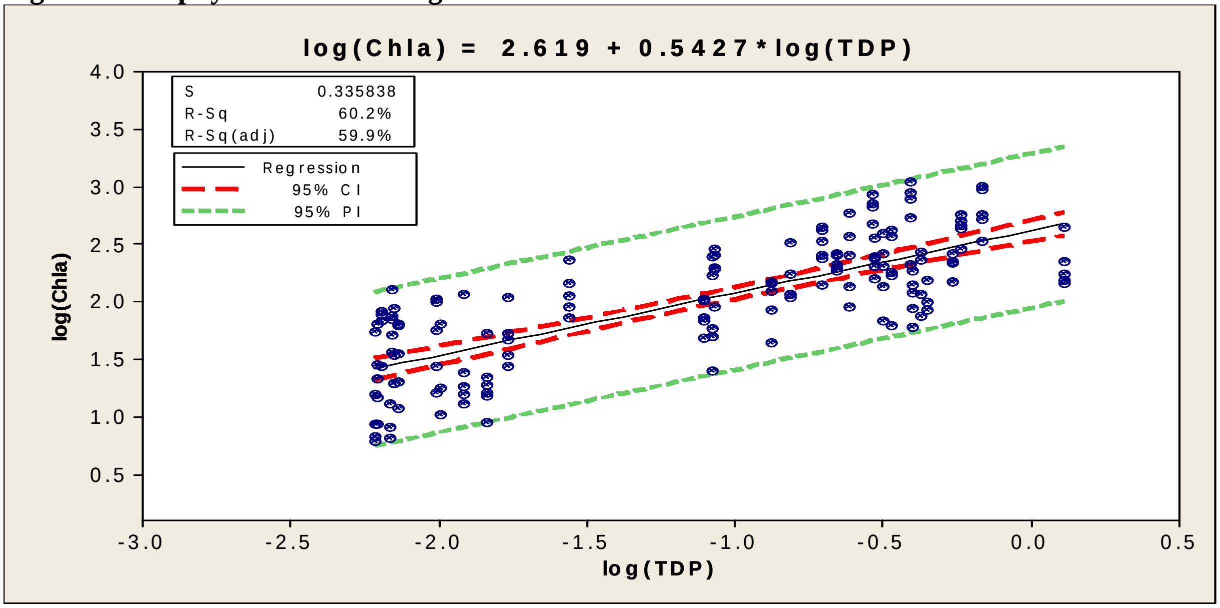


Figure 6: Periphyton-TDP Regression and TMDL End-Point in the Jackson River

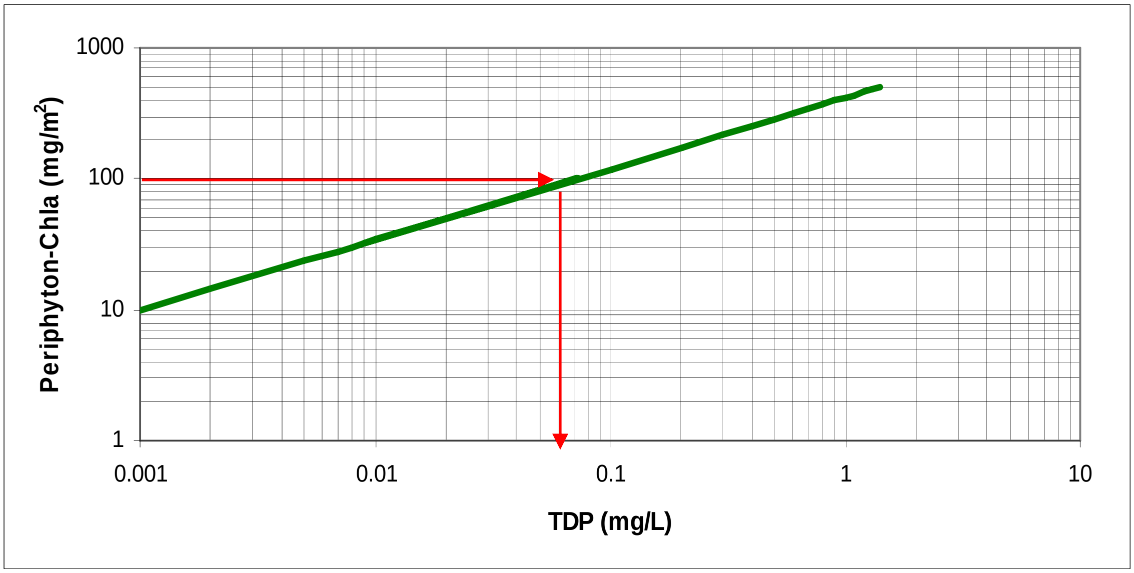


Table 2 depicts the proposed TMDL TDP endpoint, the periphyton concentration of 100mg/m2 with the resulting N:P ratio.

Table 2: Proposed Nutrient TMDL Endpoints and Resulting N:P ratios		
TDP TMDL end-point (mg/L)	Periphyton-Chla (mg/m^2)	N:P ratio
0.072	100	6.8
0.047	80	10.4

(*)calculated assuming that the nitrogen level remains unchanged in the Jackson River and at 0.49 mg/L (means of all the means at all the stations except Filtration Plant, Dunlap, and Potts)

Table 2 shows that the proposed nutrient TMDL end-point for a 100 mg/m^2 shifts the Jackson River to a "borderline" phosphorus-limited system. Consequently and to ensure that the periphyton biomass will be reduced in the Jackson River, it is necessary to shift the system to a completely phosphorus-limited one by selecting a lower periphyton target than 100 mg/m^2. Table 2 shows that a periphyton-chlorophyll concentration of 80 mg/m2 corresponds to a TDP end-point of 0.047 mg/L and shifts the Jackson River to an N:P ratio of 10.4. A ratio of N;P = 10 is commonly cited as the indicator of a complete phosphorus-limited system (Chapra 1997, Novotny 1994). It should be noted that based on periphyton studies conducted in the Jackson River, by MeadWestvaco, the average biomass N:P ratio is 7.2.

Finally, we need to convert the TDP endpoint concentration to Total Phosphorus using an average ratio of 0.75 (TDP/TP = 0.75). This ratio is based on analysis of the Chesapeake Bay Modeling Results for the James River. Consequently, the TP endpoint in the Jackson River is approximately 0.063 mg/L. Finally Table 3 presents the result of this analysis as well as other TP endpoints form different sources.

Table 3: Comparison of Potential TP TMDL Endpoints	
Source	**TP Endpoint (mg/L)**
Chesapeake Bay 2010 Cap Allocations (minimum value)[1]	0.065
VADEQ Reference Value (25th percentile)[2]	0.010
EPA Reference Value (25th percentile)[2]	0.010
Jackson River Regression (this memo)	0.063

[1] Virginia DEQ, 2006
[2] Zipper et. al, 2004

7. Data Summary

This section presents the data used in developing the regressions shown in Section 4 as well the tabular data summary of the nutrients and periphyton graphs shown in Figures 1 through 3.

7.1 Nutrient and Periphyton Data used to develop the Regression

Table 4 displays all the data used in the development of the statistical regressions.

Table 4: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	83.9
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	78.3
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	70.0
FILT	-1.2	8/11/2000	0.014	0.122	0.0016	0.0064	0.30	27.9
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	71.4
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	130.2
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	52.3
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	75.5
FILT	-1.2	8/27/2000	0.010	0.151	0.0021	0.0069	0.29	37.1
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	6.6
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	13.1
FILT	-1.2	6/6/2001	0.008	0.214	0.0019	0.0068	0.37	8.3
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	28.5
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	64.2
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	14.9
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	8.8
FILT	-1.2	6/13/2001	0.014	0.222	0.002	0.0062	0.35	21.8
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	62.9
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	36.4
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	20.6
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	12.2
FILT	-1.2	6/19/2001	0.037	0.197	0.002	0.0072	0.36	64.7
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	6.1
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	8.8
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	16.1
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	6.9
FILT	-1.2	6/25/2001	0.044	0.167	0.0017	0.0061	0.35	54.6
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	27.8
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	47.5
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	34.9
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	53.6
FILT	-1.2	7/9/2001	0.007	0.152	0.0031	0.0169	0.35	110.3
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	16.5
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	108.2
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	27.6
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	57.9
FILT	-1.2	8/1/2001	0.030	0.237	0.0025	0.0097	0.41	99.8
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	19.6
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	19.5
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	34.8
FILT	-1.2	8/13/2001	0.007	0.202	0.0042	0.007	0.33	87.6
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	18.0
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	10.5
FILT	-1.2	10/2/2001	0.042	0.141	0.001	0.01	0.33	65.3
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	117.3
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	24.5
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	13.2
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	16.1
FILT	-1.2	10/24/2001	0.014	0.098	0.0038	0.012	0.29	18.6
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	15.2
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	53.5
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	22.2
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	19.0

Table 4: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	9.0
FILT	-1.2	10/31/2001	0.014	0.104	0.0036	0.0145	0.30	16.4
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	1119.6
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	536.7
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	210.5
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	803.0
MILB	0.3	10/18/2000	0.029	0.072	0.3520	0.3917	0.42	897.8
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	151.7
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	85.1
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	126.0
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	44.3
PEDE	0.3	6/6/2001	0.048	0.188	0.0882	0.1316	0.48	147.8
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	505.5
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	436.9
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	584.0
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	293.1
PEDE	0.3	6/20/2001	0.181	0.114	0.4760	0.5732	0.60	472.7
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	156.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	455.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	225.4
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	176.9
PEDE	0.3	6/25/2001	0.058	0.127	1.0700	1.2879	0.44	144.3
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	265.2
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	225.6
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	152.5
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	217.5
PEDE	0.3	7/9/2001	0.239	0.128	0.4300	0.5379	0.72	148.7
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	404.3
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	262.8
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	203.8
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	137.2
PEDE	0.3	8/1/2001	0.009	0.194	0.2920	0.3160	0.43	68.0
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	191.8
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	91.5
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	258.4
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	199.6
PEDE	0.3	8/14/2001	0.023	0.207	0.0770	0.0845	0.42	294.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	119.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	334.6
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	110.5
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	179.2
PEDE	0.3	8/21/2001	0.026	0.111	0.1370	0.1524	0.36	117.9
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	236.2
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	147.1
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	92.8
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	114.5
PEDE	0.3	9/4/2001	0.058	0.144	0.0173	0.0272	0.44	74.1
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	239.6
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	430.5
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	143.5
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	452.4
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	335.8
MALL	8.7	11/8/2000	0.208	0.355	0.0600	0.1944	0.90	253.9
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	526.6

Table 4: Nutrient and Periphyton -Chlorophyll Data								
Station	**RM**	**Date**	**NH_4**	**NO_{23}**	**PO_4**	**TDP**	**TDN**	**Chla**
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	580.4
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	345.9
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	1032.0
MALL	8.7	12/13/2000	0.017	0.118	0.5650	0.6775	0.36	969.2
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	257.8
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	136.5
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	91.5
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	606.3
MALL	8.7	7/27/2001	0.023	0.175	0.1910	0.2420	0.43	369.7
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	49.6
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	106.7
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	104.8
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	73.2
MALL	8.7	9/4/2001	0.096	0.216	0.0708	0.0784	0.53	70.0
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	172.2
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	50.3
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	50.9
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	58.9
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	25.7
MALL	8.7	9/27/2001	0.017	0.188	0.0669	0.0838	0.42	250.9
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	187.0
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	265.6
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	213.4
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	201.1
MALL	8.7	10/3/2001	0.034	0.192	0.1400	0.2184	0.57	260.3
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	377.6
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	426.7
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	172.2
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	181.0
MALL	8.7	10/23/2001	0.055	0.150	0.2700	0.3367	0.62	63.0
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	116.1
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	75.3
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	236.5
MALL	8.7	10/30/2001	0.025	0.135	0.3080	0.4191	0.5	274.8
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	158.2
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	100.7
IDLE	5.9	10/23/2001	0.068	0.072	0.3330	0.4416	0.49	86.2
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	89.6
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	187.4
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	60.0
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	119.9
VALL	12.6	7/11/2001	0.036	0.229	0.3570	0.3966	0.51	142.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	241.9
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	362.2
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	160.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	209.5
VALL	12.6	10/23/2001	0.026	0.139	0.2570	0.2956	0.52	246.0
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	670.3
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	717.9
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	488.1
VALL	12.6	10/30/2001	0.010	0.141	0.2110	0.2891	0.52	865.2

7.2 Summary of Nutrient and Periphyton Data

Tables 5 though 7 show the tabular summaries of the TDN, TDP, and Chlorophyll in the Jackson River. These tables correspond to the data displayed in Figures 1 through 3.

Table 5: Summary of TDN Observations in the Jackson River (mg/L)								
Count	Station	Mean	Median	Min	Max	25th Percentile	75th Percentile	STDEV
106	City Filtration Plant (RM -1.2)	0.30	0.28	0.15	0.70	0.25	0.33	0.09
160	Mill Dam (RM 0.0)	0.28	0.27	0.14	0.55	0.23	0.33	0.08
170	Mill Bridge (RM 0.3)	0.53	0.45	0.23	2.33	0.38	0.54	0.29
99	Dunlap Creek (RM 0.5)	0.25	0.24	0.06	0.55	0.17	0.30	0.10
141	Fudges Bridge (RM 2.0)	0.51	0.47	0.20	1.50	0.38	0.55	0.21
113	Hercules Bridge (RM 3.7)	0.48	0.45	0.20	1.28	0.35	0.53	0.19
102	Potts Creek (RM 5.1)	0.20	0.18	0.06	0.53	0.14	0.24	0.09
146	Idlewilde Bridge (RM 5.9)	0.52	0.47	0.14	1.74	0.39	0.60	0.22
120	Mallow Mall (RM 8.7)	0.54	0.48	0.30	1.68	0.40	0.58	0.23
102	Valley Ridge BR (RM 13.0)	0.45	0.44	0.15	0.84	0.37	0.52	0.13
173	Clifton Forge (RM 19.0)	0.42	0.36	0.19	1.40	0.29	0.51	0.19

Table 6: Summary of TDP Observations in the Jackson River (mg/L)								
Count	Station	Mean	Median	Min	Max	25th Percentile	75th Percentile	STDEV
106	City Filtration Plant (RM -1.2)	0.0132	0.0081	0.0027	0.1066	0.0064	0.0133	0.0156
160	Mill Dam (RM 0.0)	0.0156	0.0087	0.0029	0.2347	0.0068	0.0145	0.0244
170	Mill Bridge (RM 0.3)	0.4689	0.2978	0.0210	5.0477	0.1424	0.5908	0.5642
100	Dunlap Creek (RM 0.5)	0.0210	0.0076	0.0026	0.5003	0.0050	0.0128	0.0597
141	Fudges Bridge (RM 2.0)	0.4533	0.3447	0.0352	4.2744	0.1625	0.5913	0.5060
113	Hercules Bridge (RM 3.7)	0.4201	0.2963	0.0266	2.8830	0.1360	0.5237	0.4343
102	Potts Creek (RM 5.1)	0.0362	0.0097	0.0042	1.6340	0.0071	0.0176	0.1643
146	Idlewilde Bridge (RM 5.9)	0.4181	0.2941	0.0365	1.7555	0.1534	0.5333	0.3793
120	Mallow Mall (RM 8.7)	0.4082	0.2813	0.0410	2.5239	0.1393	0.4737	0.4097
102	Valley Ridge BR (RM 13.0)	0.3512	0.2114	0.0335	2.8504	0.1380	0.3437	0.4366
173	Clifton Forge (RM 19.0)	0.3524	0.2382	0.0311	1.8100	0.1337	0.3850	0.3566

Table 7: Summary of Periphyton-Chlorophyll a Observations in the Jackson River (mg/m^2)								
Count	Station	Mean	Median	Min	Max	25th Percentile	75th Percentile	STDEV
212	Filtration Plant (RM -1.2)	58	41	2	555	20	78	58
82	Mill Dam (RM 0.0)	348	290	20	2393	217	413	288
66	Mill Bridge (RM 0.3)	336	261	44	1120	149	471	241
284	Play Ground (RM 1.1)	521	414	5	3627	191	687	459
428	Industrial Park (RM 3.0)	521	393	13	4433	239	649	474
20	Idlewilde Bridge (RM 5.9)	201	152	38	652	79	266	162
50	Byrd Farm (RM 7.5)	250	172	14	1059	75	418	230
197	Mallow Mall (RM 8.7)	384	247	8	2194	140	506	394
30	Valley Ridge Bridge (RM 13.0)	292	215	26	1389	147	256	285

8. References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Chapra, S.C. 1997. Surface Water Quality Modeling , WCB/McGraw-Hill Publisher .

Cooke, G.D., Welch, E.B., Peterson, S.A., and Newroth, P.R. 1993. Restoration and management of lakes and reservoirs. 2nd edition Lewis Publishers, Boca Raton, Fla.

Dodds, W.K., V.H. Smith, and K. Lohman. 2002. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Can. J. Fish. Aquat. Sci. 59: 865-874.

MeadWestvaco Corporation 2003. Development and Calibration of the Jackson River Periphyton Model.

Minitab® Statistical Software, Release 14.20. Minitab Inc.

Novotny V. and H. Olem 1994. Water Quality Prevention, Identification, and Management of Diffuse Pollution. John Wiley & Sons, Inc. Publishers.

Pennsylvania DEP, April 2005. Final Report Total Maximum Daily Load for Skippack Creek, Montgomery County, Pennsylvania,

Smith, V.H. 1998. Cultural eutrophication of inland, estuarine, and coastal waters. *In* Successes, limitations and frontiers in ecosystem science. Edited by M.L. Pace and P.M. Groffman. Springer-Verlag, New York. pp. 7–49.

Smith, V.H., Tilman, G.D., and Nekola, J.C. 1999. Eutrophication: effects of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environ. Pollut. 100: 179–196.

Welch, E.B., Jacoby, J.M., Horner, R.R., and Seeley. M.R. 1988. Nuisance Biomass levels of Perihytic Algae in Streams. Hydrobiologia, 157: 161-168.

Virginia DEQ. 2006. *Freshwater Nutrient Criteria-Analysis of Downstream Loading Effects*.

Zipper, C.E, Benfield, E.F, Dillaha III, T.A, Gizzard, T.J., Hershner, C.H., Wu-Seng, L., Ney, J.J., Shabman, L.A., Walker, J.L, Yagow, E.R., and Younos, T. 2004. *Report of the Academic Advisory Committee to Virginia Department of Environmental Quality- Freshwater Nutrient Criteria*. Virginia Water Resources Research Center.